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Brake shoe tests

Railway Electrical Engineering

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BRAKE SHOE TESTS

BY

ROSS PRESTON BRALEY
WILBUR JAMES DIXON

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

RAILWAY ELECTRICAL ENGINEERING, ROSS PRESTON BRALEY
IN
RAILWAY MECHANICAL ENGINEERING, WILBUR JAMES DIXON

COLLEGE OF ENGINEERING

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DEGREE OF Bachelor of Science in Railway Engineering

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BRAKE SHOE TESTS.

Introduction.

During the years 1878-79 Sir Douglas Galton and Mr George Westinghouse conducted a systematic series of tests to determine the value of the coefficient of friction between brake-shoes and the wheel in braking a railway car. As the result of these tests a number of important conclusions were deduced and reported to the Institue of Mechanical Engineers of London, April 1879. The conclusions drawn from the tests made at this early date have in general been found to hold true up to the present time.

One of the most important facts brought out by the Galton tests is what may be called the law of variations. This law states that the coefficient of friction increases with a decrease in speed. Results of tests have shown that with a constant pressure on the brake-shoe the coefficient of friction between the shoe and wheel when the car is moving at a speed of 60 miles per hour is only about one half as great as the coefficient of friction when the speed has been reduced to 20 miles per hour. Therefore, if the pressure brought to bear upon the brake-shoe is great enough to produce the proper braking effect when the speed is 60 miles per hour, this pressure would be too great as the train slowed down. This is because as the speed diminished the coefficient of brake-shoe friction increased to such an extent as to finally stop the wheels revolving and cause them to slide upon the rails. Experiments have proven that, when the wheels slide upon the rails, the resistance to the movement of the train is only about one third of what it would be if the wheels were braked to a maximum and still allowed to revolve. The reason for this is that when the wheels are not revolving but

skidding upon the rails, the resistance caused by the brake-shoes pressing against the wheels ceases since there is no relative motion between the two. This being the case, the only force producing retardation of the movement of the car is the resistance set up between the small surface of the wheels in contact with the rail under a pressure which is simply the weight of the car alone.

In order to obtain the highest efficiency in stopping a train it is necessary to maintain a uniform braking effort throughout the stop. For this reason the high-speed air brake has been developed and generally adopted for passenger service. With the high-speed brake the train line pressure is increased from 70 to 110 pounds per square inch. Thus when the proper reduction is made in the train line the cylinder pressure will build up to about 85 pounds per square inch. This causes a great pressure to bear upon the piston in the brake cylinder, which in turn transmits this force through the system of brake levers to the brake shoe. Such a braking pressure as is thus obtained is safe for high speeds around 50 miles per hour, but would cause the wheels to slide upon the rails as the speed became materially decreased. This difficulty however, has been overcome by attaching an automatic reducing valve to the brake cylinder. Whenever the pressure within the brake cylinder becomes greater than 60 pounds per square inch, this valve automatically but slowly reduces the pressure to 60 pounds.

With the high-speed brake it is therefore possible to secure a heavy pressure on the brakes at high speed where such action is safe and efficient. Then as the speed decreases the braking pressure gradually becomes less, due to the action of the automatic reducing valve. This valve is supposed to be so construct-

ed as to maintain a varying braking pressure which would give a safe maximum for any speed. If such action is perfectly accomplished, a uniform braking effort will be maintained from a high speed down to the point of stopping. That is, the curve for braking effort would be a straight horizontal line.

Object of Thesis.

The object of this thesis has been to investigate the true action of the high-speed brake while braking a car from a speed of 60 miles per hour to a stop. Special attention has been given to the results of these tests to determine whether the braking effect remained constant as the speed decreased.

Apparatus Used.

This work has been chiefly of an experimental nature. The apparatus used was as follows. A brake-shoe testing machine built according to Master Car Builders standards and specifications. A Sellers dynamometer, which formed part of the testing machine, registered the tangential pull between the brake-shoe and the car wheel. A steel wheel, similar to those used in passenger service, was used. The braking pressure was produced by a high-speed air brake. A description of this apparatus will be found under the subject of tests.

Since all the apparatus used was new and had only recently been installed, it was necessary to calibrate the various recording parts in order to ascertain their accuracy. This work included the calibration of the dynamometer and of the Boger speed recorder. It was also necessary to determine the exact travel of the paper on which the dynamometer traces the braking curves.

Calibration of Boyer.

The Boyer speed recorder gave the speed at miles per hour at which the car wheel was moving. This apparatus was driven from the main shaft of the testing machine by means of a combination of a chain and belt drive. This arrangement was such as to permit very little lost motion in the drive. The calibration was accomplished in the following manner. The speed of the car wheel was brought up to over 60 miles per hour. Then the clutch connecting with the driving engine was thrown out. The car wheel continued to revolve at high speed due to the energy stored up in the fly-wheel which was located on the same shaft as the car wheel. One man held an accurate tachometer on the main shaft of the machine while another watched the dial of the Boyer recorder. Simultaneous readings were taken by each man as the speed decreased from 60 miles per hour. Table No. 1 shows the miles per hour by the recorder and the corresponding number of revolutions per minute of the car wheel. The revolutions per minute of the car wheel was reduced to miles per hour in the following manner. The diameter of the car wheel was 33 inches.

$$\pi \times 33'' = 103.67 \text{ inches} \quad \text{or } 8.64 \text{ feet.}$$

$$\frac{5280}{8.64 \times 60} = 10.185 = K$$

$$\frac{\text{R. P. M. (by tachometer)}}{K} = \text{M. P. H.}$$

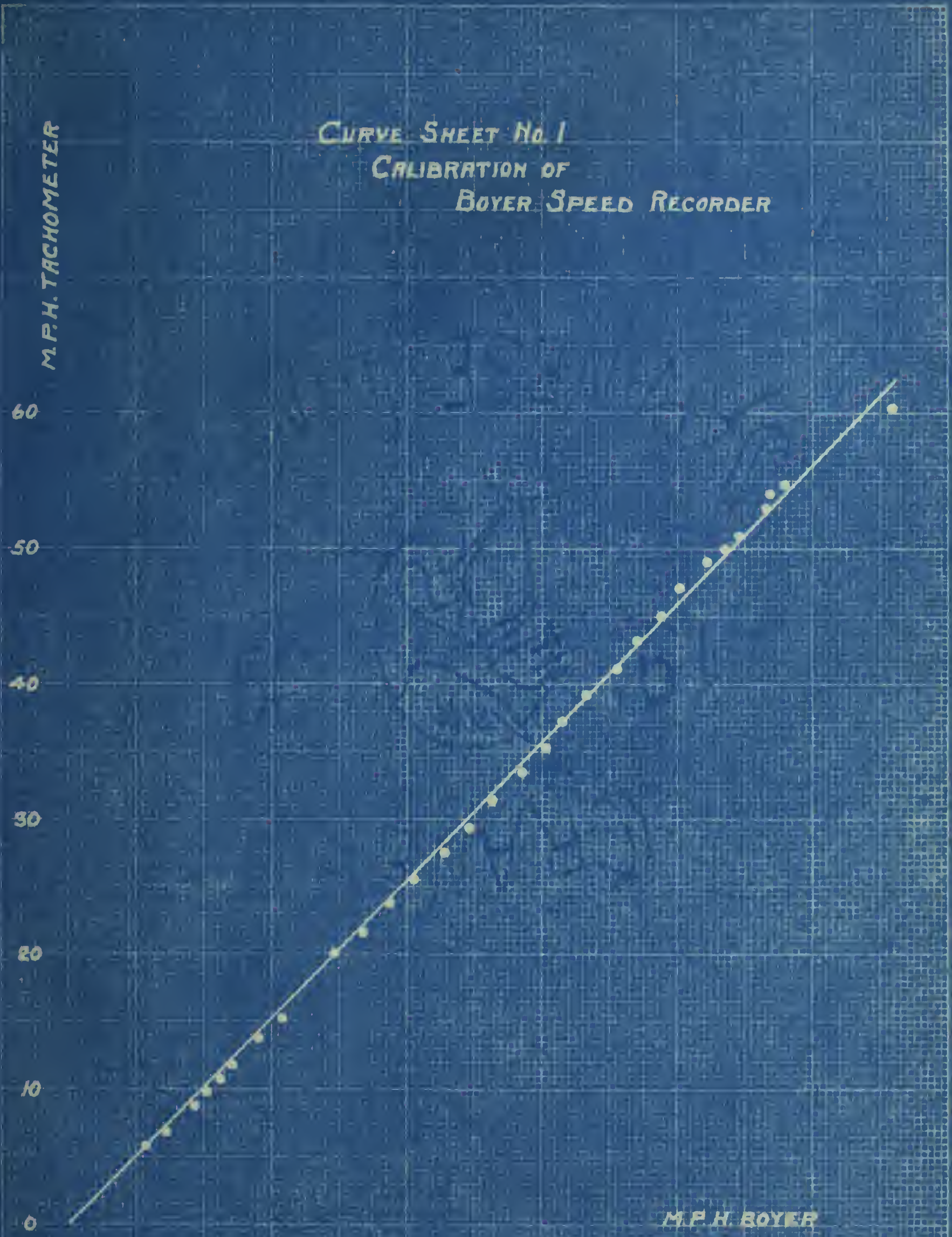
The results obtained are shown in graphical form by curve No. 1.

Paper Travel.

The record of the braking effect as shown by the dynamometer was traced upon a strip of paper seven inches wide, as it was wound over a drum. The movement of the paper was proportional to the speed

TABLE No. 1

TACHOMETER R.P.M.	TACHOMETER READING IN M.P.H.	BOYER READING IN M.P.H.
615	60.4	60.8
558	54.7	53.0
550	54.0	52.3
540	53.0	51.5
520	51.0	49.5
510	50.1	48.5
500	49.1	47.25
480	47.2	45.8
460	45.2	43.75
440	43.25	42.0
420	41.2	40.5
400	39.25	38.25
380	37.3	36.5
360	35.35	35.25
340	33.4	33.5
320	31.4	31.25
300	29.45	29.5
280	27.5	27.8
260	25.5	25.5
240	23.75	23.8
220	21.6	21.9
200	19.65	20.0
160	15.7	15.9
140	13.75	14.0
120	11.8	12.1
110	10.8	11.1
100	9.8	10.25
90	8.85	9.25
70	6.87	7.2
60	5.9	5.8



EUGENE DIETZGEN CO., CHICAGO.

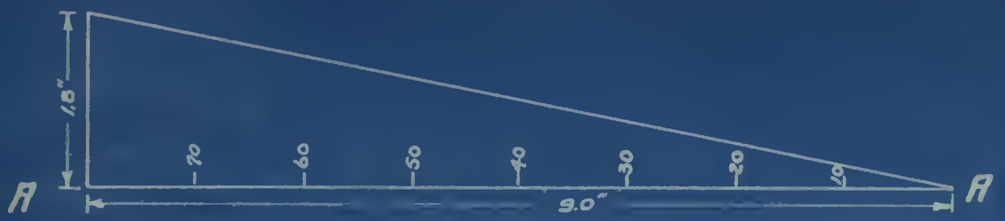
of the car wheel. A pencil attached to a magnet that was controlled by a clock, marked second intervals on the moving paper. The exact travel of the paper was obtained by running the testing machine for a short time with a speed counter held on the main shaft during the entire period the machine was in motion. Several runs of this nature were made in order to obtain an average. Since the exact number of revolutions was known each time, by measuring the length of paper that unrolled during the period the machine was in motion, the travel of the paper per car mile was calculated. From these tests the paper travel was found to be 80.95 inches per car mile or .01533 inches per foot of linear travel of the car. Therefore for a speed of 60 miles per hour or 88 feet per second the paper travel was 88 x .01533 or 1.35 inches per second. That is for a speed of 60 miles per hour the distance between two adjacent second marks on the paper was 1.35 inches.

The travel of the paper being proportional to the speed of the car wheel it was possible to construct a scale whereby the speed in miles per hour for any second interval could be read directly. Such a scale is shown in Fig. 1. The idea involved is that of the proportion between the sides of similar triangles. The maximum height of the triangle (Fig. 1) was taken as 1.8 inches. This distance corresponded to the paper travel for one second for a speed of 80 miles per hour. The miles per hour scale was plotted in equal spaces along the side AA of the scale, while the ordinates were equal to the travel of the paper per second for that respective speed. By placing the scale with the side AA perpendicular to the line on the paper on which the seconds were checked off, the speed in miles per hour for any time interval could be read directly.

Calibration of Dynamometer.

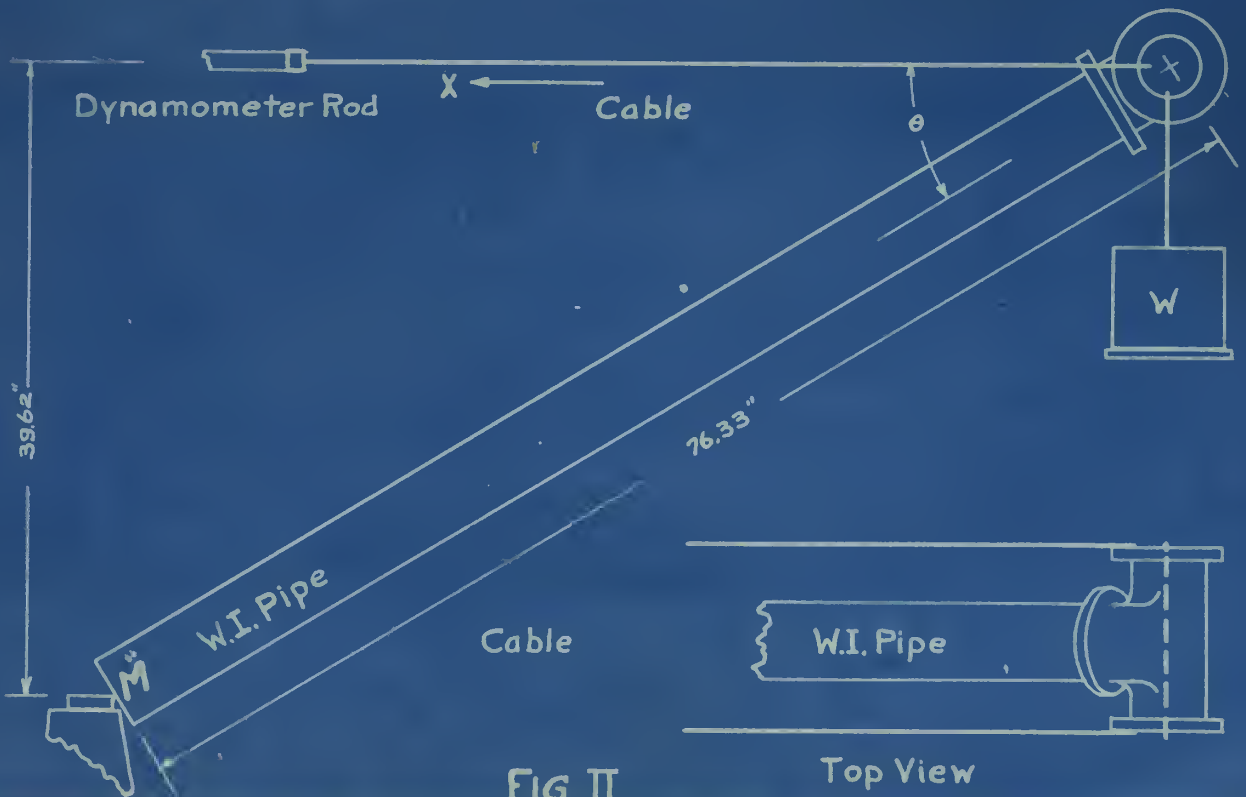
The ordinate of the curve made by the dynamometer at any point indicated the braking effort being exerted at that point. Thus by simply determining the speed at any given point by the method just described and then measuring the ordinate at that point the braking effort at that particular speed could be readily obtained from the dynamometer calibration curve. The data for this calibration curve was obtained by the special apparatus shown by Fig. II. The dynamometer rod which transmitted the braking effort of the brake shoe to the dynamometer was normally fastened by a yoke to both sides of the brake-shoe holder. In testing the dynamometer this rod was disconnected from the sides of the brake-shoe head. A 5/8 inch steel cable was fastened to one eye of the yoke then brought out on a horizontal line and passed through the tee on the end of the wrought iron pipe as shown in Fig. II. Then the loose end of the steel cable was brought back and fastened to the opposite eye of the yoke. The cable was free to move in the tee at the end of the pipe, thus producing an equal tension in the parallel lines of cable. As shown in Fig. II, the four inch iron pipe served as a strut. It was supported at the top or tee end by the cable passing through it. The lower end pressed against a steel knife edge at M. This knife edge was securely fastened to a part of the machine foundation.

The cable being attached directly to the dynamometer rod, any pull in the cable would cause an ordinate to be traced on the paper by the recording apparatus. A zero reading was first taken without any pull whatever on the pull rod. Then weights of known value were applied at W. These weights plus the constant weight



1.8"
A
9.0"
A

Fig. I

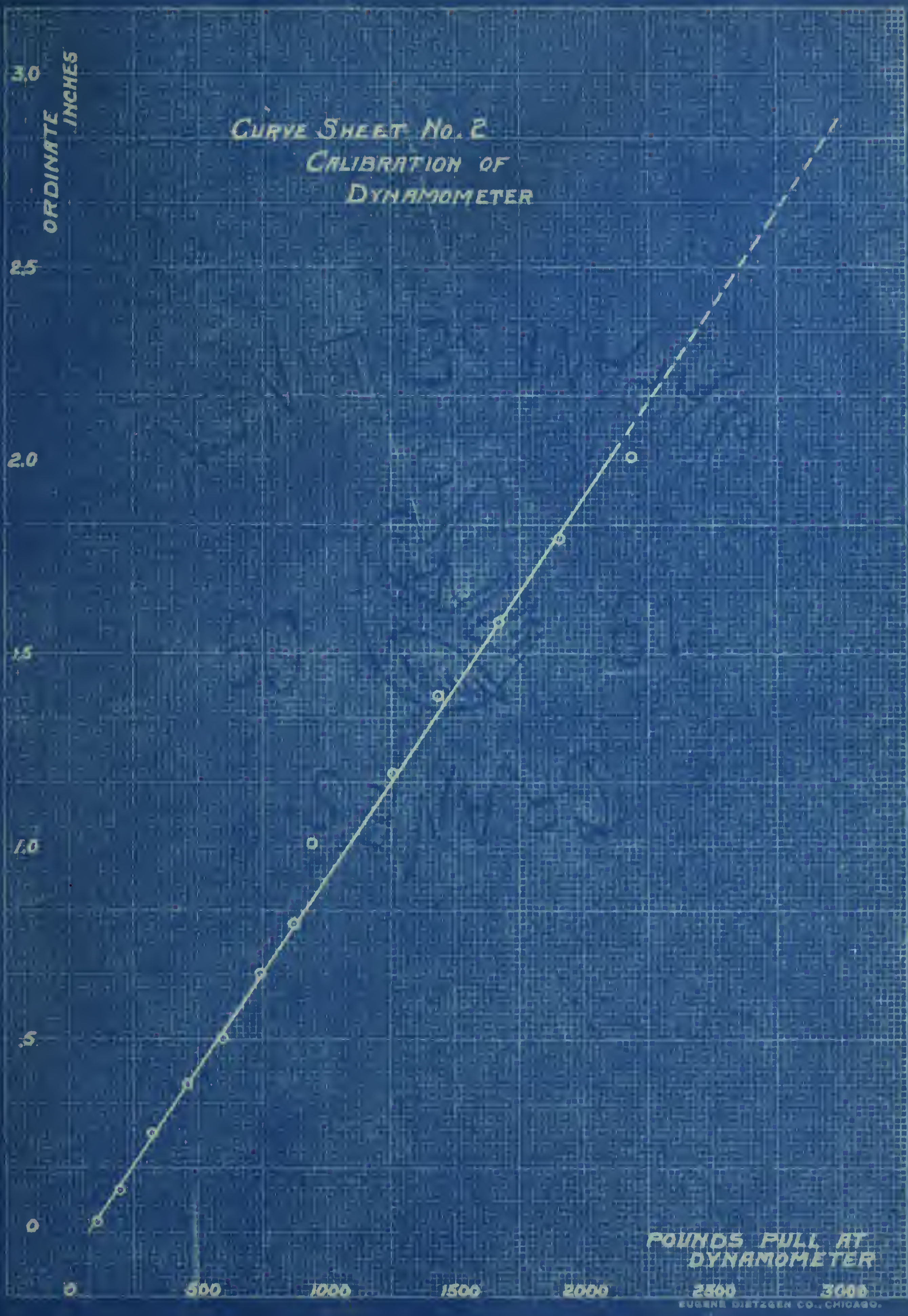


Dynamometer Rod
X
Cable
θ
W
39.62"
76.33"
W.I. Pipe
M
Cable
W.I. Pipe
Top View

Fig. II

TABLE No. 2

WEIGHT POUNDS	ORDINATE INCHES	POUNDS PULL AT DYNAMOMETER	
61	.03	100.5	
112	.11	184.3	
195.25	.26	321.5	
279	.38	459	
364	.5	598	
448.75	.67	738	
531.5	.8	875	
565.5	1.01	931	
763	1.19	1235	
888	1.39	1460	
1015	1.58	1670	
1153	1.8	1900	
1320.5	2.07	2180	



CURVE SHEET NO. 2
CALIBRATION OF
DYNAMOMETER

of the strut etc. caused ordinates of varying lengths to be traced on the paper. Care was taken to secure a new zero base line several times during the test. By means of very careful measurements the exact dimensions as shown in Fig. II. were obtained. From these measurements the angle θ was calculated. Since the movement of the dynamometer was never over one fourth of an inch, the angle θ could be safely taken as constant. The cotangent of the angle θ was found to be 1.645. Therefore from Fig. II,

$$X = \cot \theta \quad W, \quad \text{or } X = 1.645W$$

X = the pull on the dynamometer rod and W = the weight applied at the end of the strut. Table 2 gives the data obtained from these tests, while curve No. 2 shows the calibration curve of the dynamometer.

Description of Tests.

Fig. III shows the arrangement of the apparatus as used in making the braking tests. The air brake used was a Westinghouse high speed passenger brake with a 12 inch cylinder. The car wheel was steel tired, and 33 inches in diameter. A brake shoe was used that was manufactured by the American Brakeshoe & Foundry Co. The shoe was of the reinforced type bearing the marking, K. Pat. 4-11-93. This shoe was taken at random from stock at the Big Four Shops at Urbana.

The pressure brought to bear upon the brake shoe was produced by the air brake. This action was accomplished in the following manner. When air was admitted to the brake cylinder the piston within the cylinder was pushed forward causing the piston rod X (Fig. III) to move out and strike the knife edge on the bell crank at Y. The travel of the piston was fixed at eight inches, this

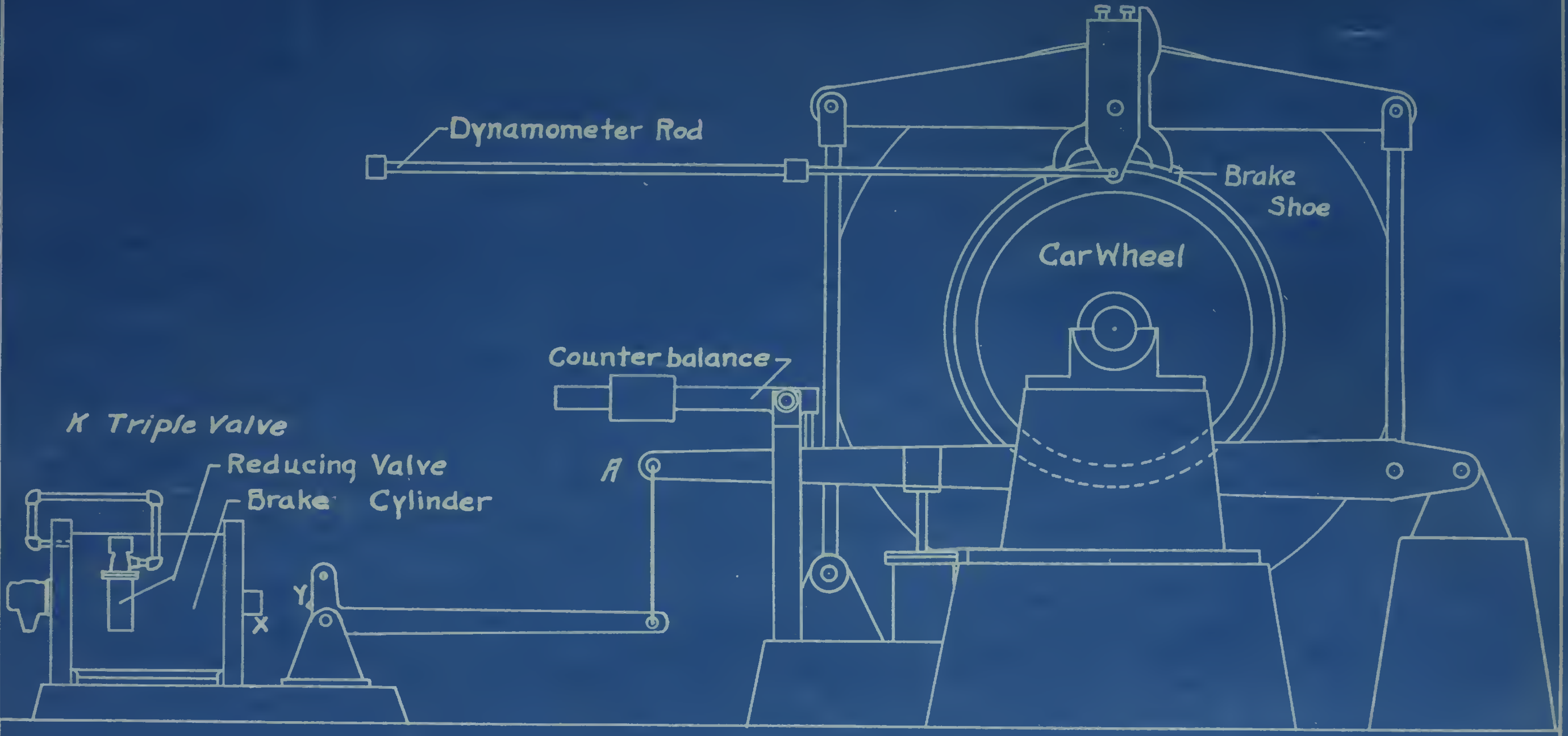

Dynamometer Rod
Brake Shoe
Car Wheel
Counter balance
K Triple Valve
Reducing Valve
Brake Cylinder
A
Y
X

FIG. III

being the standard running piston travel used in service today. The force of the piston rod pressing against the bell crank at Y was transmitted by the bell crank to A and then through the regular system of levers of the testing machine until the pressure was brought to bear directly upon the brake shoe. The counter balance shown in Fig. III was so arranged as to just lift the shoe clear of the wheel when the brakes were not applied.

The system of levers on testing machine was of the ratio of 24 to 1. That is one pound applied at A would produce 24 pounds pressure upon the brake shoe. This arrangement enabled the use of a comparatively small weight at A in order to produce a large braking pressure on the shoe. In order therefore, to apply the pressure within the brake cylinder to the shoe it was necessary to use some means of reducing this force before it was applied at A. This was accomplished by means of the bell crank arrangement shown in Fig. III. The ratio of the arms of the bell crank was 1 to 24. This ratio was just the reverse of the lever ratio of the machine. Therefore it can be readily seen that, barring slight losses due to pin friction, the pressure set up within the brake cylinder was applied directly to the brake shoe, and was the same as the shoe pressure in the case of an 8 wheel car having a lever ratio of 8 to 1, efficiencies being practically the same in each case.

In making the tests the car wheel was first brought up to a speed of over 60 miles per hour. Then the driving clutch was thrown out. When the Boyer recorder registered 60 miles per hour a strong application of the air brake was made. This in most of the tests caused the pressure in the brake cylinder to build up to over 80 pounds per square inch. The automatic reducing valve was set for

60 pounds. Therefore, as soon as these high pressures formed in the brake cylinder, the reducing valve would gradually reduce the pressure to 60 pound per square inch. For a pressure of 88 pounds in the 12 inch cylinder a brake shoe pressure of 9,953 pounds was produced. With the pressure reduced to 60 pounds the braking pressure would only be 6,785 pounds. The higher pressurewould be safe only for high speed around 60 miles per hour, while the lower pressure could be used for any speed.

The tests were numbered from one to ten in the order in which they were taken. By the use of guages it was possible to determine the exact pressure in the auxillary reservoir and train line. The pressure that built up within the brake cylinder was observed in the same manner. In some cases the wheel stopped revolving before the blowdown ceased. Whenever this happened the cylinder pressure at the point of stopping was observed. Any unusual item connected with any of the tests was noted and will be found recorded in the tables of data.

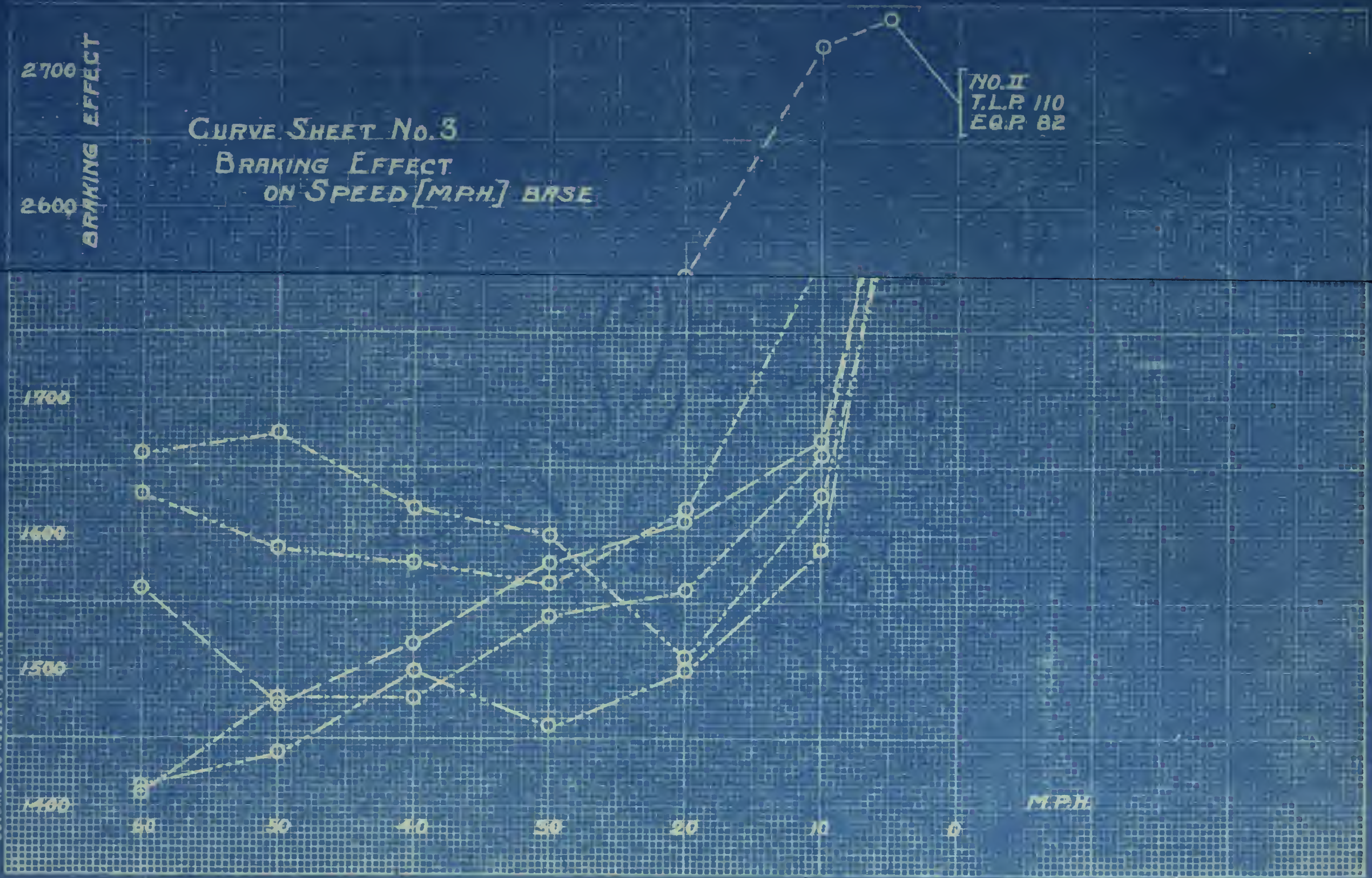
Results of Tests.

Table 3 gives the complete data of the tests with respect to the decreasing speed. The braking effects plotted on a speed base are represented by the curves shown on sheet No. 3. The numeral attached to each curve signifies the serial number of the test. The letters T. L. P. stand for the train line pressure, while E. Q. P. is an abbreviation for equalizing pressure within the brake cylinder.

Tables 4, 5, and 6 give the braking effect for distances covered in feet after the brake was applied. In securing this data several sections were chosen from each test curve where the ordinate

TABLE No. 3

No.	I		II		III		IV		V		VI		VII		VIII		IX		X	
TRAIN LINE PRES.	110		110		70		68		110		68		70		114		102		113	
EQUALIZING PRES.	83		82		48		47		80		47				86		74		83	
PRES AT STOP	65		66						LEAKED DOWN TO 76 BLOW-DOWN EXHAUST PLUGGED		EMERGENCY		CYL. PRES BUILT UP BY T. LINE LEAKAGE TO 22 AT STOP CYL. PRES AT APP. 13		66 BLOW-DOWN 12 SEC. AFTER STOP		BLOW-DOWN TO 60 RAN 23 SEC. AFTER BLOW-DOWN		RAN 28 SEC. AFTER BLOW-DOWN REDUCING VALVE #2	
M.P.H.	ORDINATE In.	BRAKING EFFECT	ORD.	B.E.	ORD.	B.E.	ORD.	B.E.	ORD.	B.E.	ORD.	B.E.	ORD.	B.E.	ORD.	B.E.	ORD.	B.E.	ORD.	B.E.
60	1.88	2010	1.83	1960	1.45	1560	1.3	1410	1.87	1995	1.54	1660	.94	1040	1.86	1990	1.52	1630	1.3	1415
50	1.83	1955	1.79	1890	1.36	1475	1.37	1480	1.95	2120	1.56	1675	1.015	1120	1.92	2040	1.48	1590	1.33	1440
40	1.83	1955	1.73	1850	1.41	1520	1.37	1480	1.86	1990	1.51	1620	1.05	1150	1.75	1870	1.47	1580	1.39	1500
30	1.8	1925	2.1	2230	1.47	1580	1.43	1540	1.89	2020	1.49	1600	1.07	1170	1.73	1850	1.46	1565	1.35	1460
20	1.85	1975	2.4	2550	1.5	1610	1.44	1560	1.87	1995	1.4	1510	1.13	1240	1.81	1925	1.51	1620	1.39	1500
10	2.18	2315	2.57	2720	1.55	1670	1.54	1660	2.1	2230	1.52	1630	1.2	1310	1.86	1990	1.69	1810	1.53	1640
5	2.3	2440	2.58	2740	1.75	1875	1.79	1890	2.21	2335	1.72	1840	1.3	1415	2.1	2230	1.83	1955	1.75	1875



CURVE SHEET No. 3
BRAKING EFFECT
ON SPEED [M.P.H.] BASE

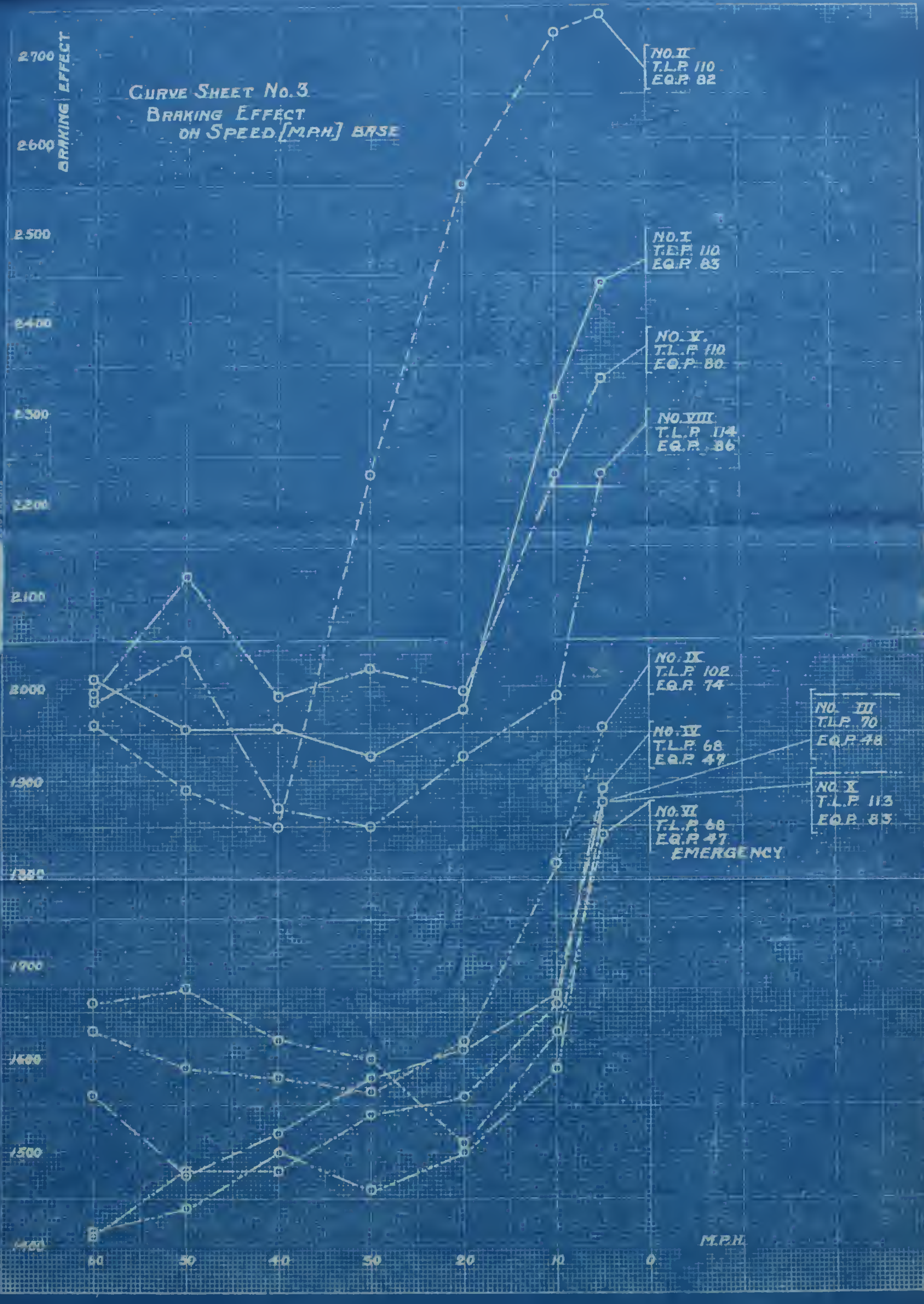


TABLE No. 4

No. OF TEST	I.	II.	III.
TRAIN LINE PRESSURE	110	110	70
EQUALIZING PRESSURE	83	82	48
PRESSURE AT STOP	65	66	

DISTANCE IN FEET TRAVELED AFTER BRAKES WERE APPLIED	ORDINATE	BRAKING EFFECT	DIST.	ORD.	B.E.	DIST.	ORD.	B.E.
0	1.88	2015	0	1.83	1960	0	1.45	1565
298	1.855	1975	251	1.79	1915	231.5	1.445	1560
625	1.83	1955	585	1.71	1825	556.5	1.42	1530
883	1.815	1940	801	1.68	1780	827	1.38	1490
1113	1.825	1950	1000	1.69	1790	1125	1.38	1490
1214.5	2.015	2150	1177.5	1.74	1865	1353	1.39	1500
1250	2.24	2375	1252	1.805	1925	1643	1.395	1510
			1379	1.96	2075	1917	1.405	1515
			1552.5	2.225	2360	2111	1.42	1530
			1670	2.49	2635	2279	1.455	1570
						2661	1.485	1590
						2794	1.49	1600
						2877	1.525	1640
						2918	1.66	1775

TABLE No. 5

No. OF TEST	IV	V	VI
TRAIN LINE PRESSURE	68	110	68
EQUALIZING PRESSURE	47	80	47
PRESSURE AT STOP		LEAKED DOWN TO 76 BLOWDOWN EXHAUST PLUGGED	EMERGENCY

IV			V			VI		
DISTANCE IN FEET TRAVELED AFTER BRAKES WERE APPLIED	ORDINATE	BRAKING EFFECT	DIST.	ORD.	B.E.	DIST.	ORD.	B.E.
0	1.3	1410	0	1.87	1995	0	1.34	1655
500	1.33	1440	196	1.88	2010	261	1.535	1650
968	1.37	1475	341	1.915	2040	522	1.54	1655
1646	1.375	1480	476.5	1.945	2065	732	1.55	1665
2338	1.4	1510	672.5	1.91	2035	878.5	1.58	1700
2818	1.435	1550	882.5	1.865	1985	1278.5	1.55	1665
3002	1.49	1600	1201.5	1.875	1995	1485.5	1.49	1600
3064	1.665	1785	1439.5	1.89	2015	1928.5	1.44	1550
			1566	1.905	2030	2471.5	1.405	1515
			1619.5	2.075	2210	2647	1.425	1540
						2734	1.485	1595
						2783	1.62	1735

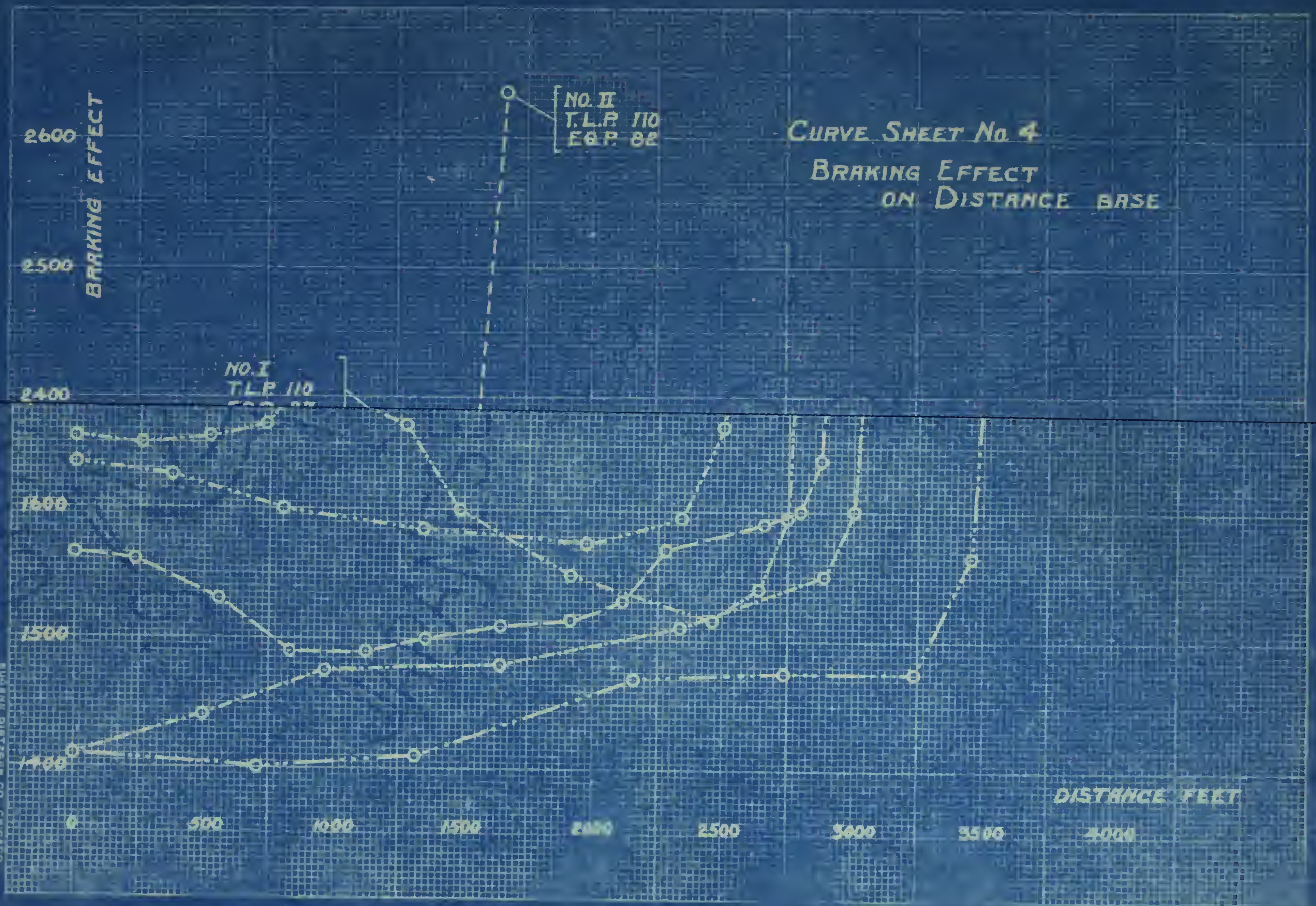
TABLE No. 6

NO. OF TEST	VIII		IX			X		
TRAIN LINE PRESSURE	114		102			113		
EQUALIZING PRESSURE	86		74			83		
PRESSURE AT STOP	66							
	BLOWDOWN 12 SEC. AFTER STOP		BLOWDOWN TO 60 RAN 23 SEC. AFTER BLOWDOWN			RAN 28 SEC. AFTER BLOWDOWN REDUCING VALVE #2		
DISTANCE IN FEET TRAVELED AFTER BRAKES WERE APPLIED	ORDINATE	BRAKING EFFECT	DIST.	ORD.	B.E.	DIST.	ORD.	B.E.
0	1.86	1990	0	1.52	1635	0	1.3	1410
414	1.928	2060	375	1.51	1625	712	1.285	1400
629	1.85	1975	803	1.49	1600	1314	1.3	1410
890	1.76	1870	1341	1.475	1585	2164	1.36	1470
1060	1.71	1825	1971	1.465	1575	2740	1.37	1475
1275	1.67	1780	2348	1.485	1595	3234	1.37	1475
1451	1.73	1835	2501	1.535	1665	3454	1.46	1565
1598	1.78	1875	2561	1.625	1740	3518.5	1.64	1750
1771	1.835	1960	2602.5	1.76	1875			
1800	1.885	2010						

was nearly constant. The value of the average ordinate for each section was taken from the dynamometer calibration curve. Since it was found that one foot of car wheel travel caused .0153 inches of paper travel, by simply measuring from some point in the chosen section back to the beginning of the curve, the distance in feet that the car wheel had traveled up to that point was readily computed. Curve Sheet No. 4 shows results of tests plotted on a distance base. All the curves start at a zero distance, that is the deceleration from 60 miles per hour is just beginning. The curves shown on sheet No. 4 do not represent maximum values of braking effect, but rather average values over the various sections taken on the test curves.

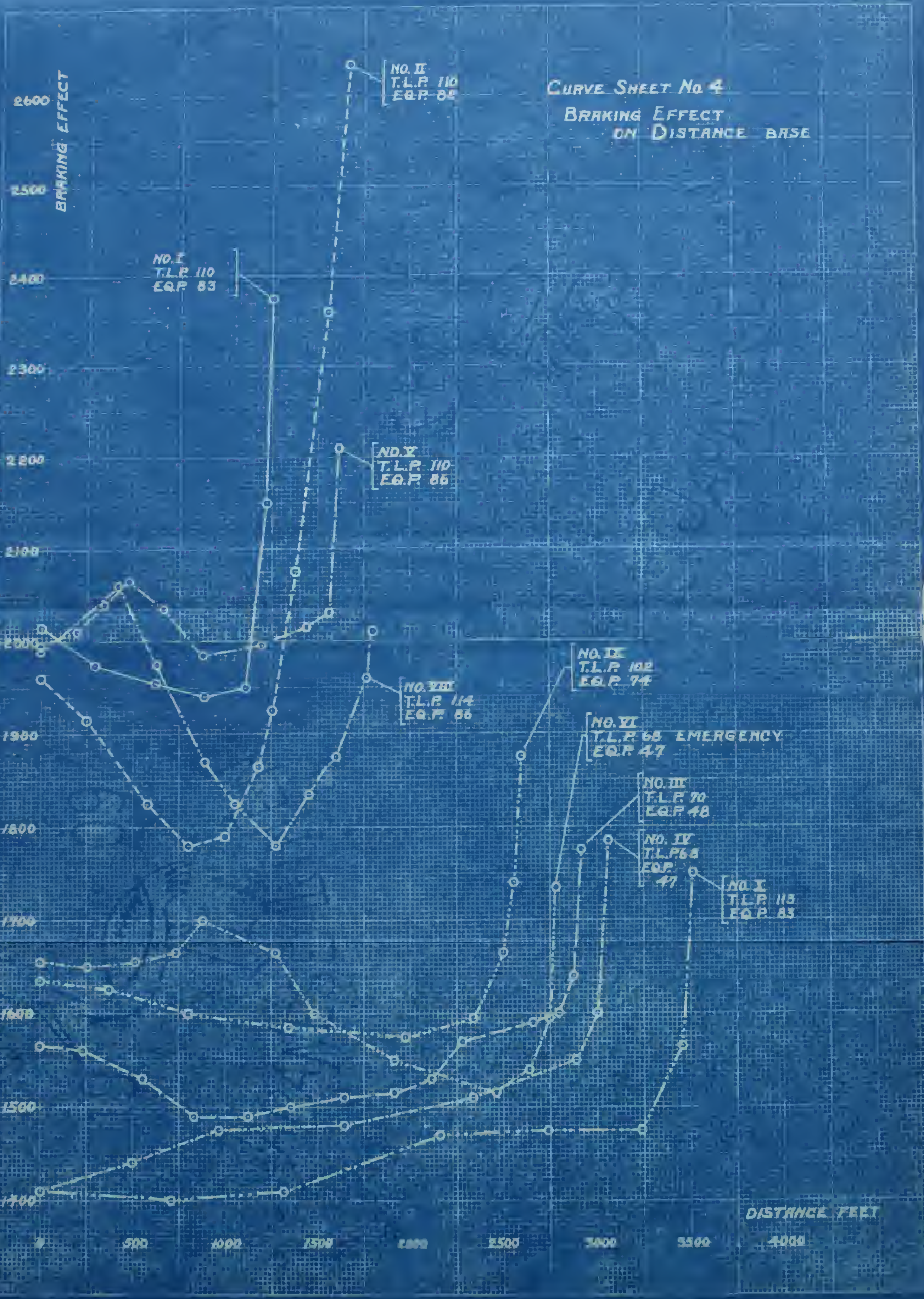
From Sheet No. 3 it can be readily seen that a greater braking effect was obtained at high speeds when the high air pressure was used. This fact is also brought out by the curves on Sheet No. 4. When the high braking pressures were used a stop was effected in a much shorter distance than was the case when lower pressures were applied. Test No. X was an exception to the above statement. For this test a different reducing valve was used which did not work efficiently. No curves were plotted for test No. VII because with such a low brake pressure, the results obtained could not be plotted on the curve sheets to the scale that has been used.

The curves on Sheets 3 and 4 have a somewhat distorted appearance. This is due to the fact that the ordinates are four times as great as the abscissae. If the coordinates of these curves were equal these curves would be more horizontal in nature and thus show more clearly a more uniform braking effect. However from these curves it has been found that the deceleration has been nearly constant.



Curve Sheet No. 4

Braking Effect on Distance base


CURVE SHEET NO. 4
BRAKING EFFECT
ON DISTANCE BASE
BRAKING EFFECT
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
0
500
1000
1500
2000
2500
3000
3500
4000
DISTANCE FEET
NO. II
T.L.P. 110
EQ.P. 85
NO. I
T.L.P. 110
EQ.P. 83
NO. V
T.L.P. 110
EQ.P. 86
NO. VIII
T.L.P. 114
EQ.P. 86
NO. IX
T.L.P. 102
EQ.P. 74
NO. VI
T.L.P. 68 EMERGENCY
EQ.P. 47
NO. III
T.L.P. 70
EQ.P. 48
NO. IV
T.L.P. 68
EQ.P.
47
NO. X
T.L.P. 115
EQ.P. 83

The actual deceleration for test No. VIII was obtained by determining the exact speed during each second interval. It was found that the drop in speed was almost proportional to the time. Curve No. 5 shows the deceleration from 60 miles per hour under the conditions of test No. VIII. It can be seen from this curve that the deceleration approaches very closely to a straight line.

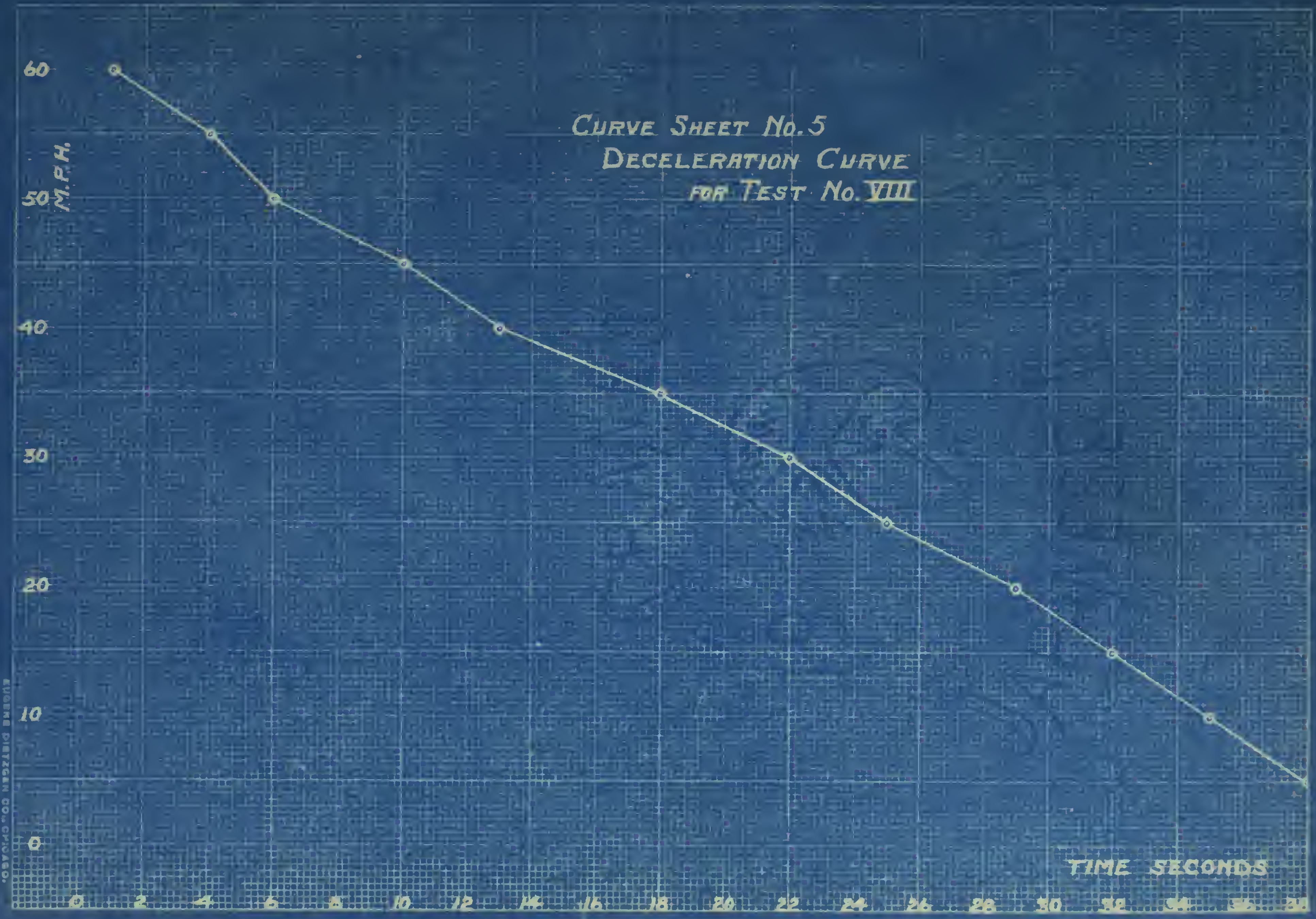
Force = mass x acceleration.

Braking effect = mass x deceleration.

The mass was known to be constant and the deceleration has been shown to be approximately constant. Therefore the braking effect must have been constant.

Conclusions.

These tests show in a general way that the high speed brake does more efficient braking at high speeds than can be accomplished by the use of lower initial pressures. Also for ordinary brake shoes as used in common practice today, the high speed brake produces a fairly uniform braking effect from high speeds down to about the point of stopping. However, the complex nature of fluctutations of the coefficient of friction make it impossible to formulate any conclusions except those of a general nature.



CURVE SHEET No. 5
DECELERATION CURVE
FOR TEST No. VIII

EUGENE DIETZGEN CO., CHICAGO.